USE OF UTERINE ELECTROMYOGRAPHY (EMG) FOR ESTIMATION OF UTERINE CONTRACTILITY AND CERVICAL DILATION DURING THE 1ST STAGE LABOR IN PREGNANT WOMEN

A thesis submitted to the University of Arizona College of Medicine – Phoenix
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Acknowledgments

I appreciate the guidance and support of Dr. R.E. Garfield. I also acknowledge the support of Dr. McEchron, and Mr. Paul Kang for help with statistical analysis and the motivation to continue driving forward.

Abstract:

Introduction: Within Labor and Delivery (L&D), current methods for measuring pre-term and term labor are subjective, invasive, and crude. We show in this study that these archaic means can be replaced with a non-invasive objective means of measurement of uterine electrical activity, electromyography (EMG). Labor and delivery in pregnant women occurs in three stages: The 1st stage begins with the onset of stronger uterine contractility and progressive cervical dilation. The onset and development of labor are commonly monitored with crude and inaccurate instruments and methods: a force transducer (tocodynamometer or TOCO) strapped to the abdominal surface to measure uterine contractility and subjective digital exams to estimate effacement and cervical dilation. Prior studies have shown that electrical activity propagation is the underlying basis for uterine contractility as it is in all muscles including the heart, skeletal and smooth muscles. In a similar manner to cardiac muscle, electrical activity can be accurately estimated in the uterus via EMG. In the uterus, electrical activity consists of bursts of spikes and the characteristics of the bursts are responsible for the frequency, duration, and force of contractions.

Methods: EMG records were obtained from the abdominal surface of pregnant nulliparous women with normal 1st stage of labor: Study 1, (n=195 patients, 1 record/patient) before and following 100% effacement and during cervical dilation (1 to 10 cm) from a database maintained by R.E. Garfield. Uterine electrical bursts were recorded and analyzed with ADInstruments (Castle Hill, Australia) hardware and software. The following EMG burst characteristics were examined vs. effacement and cervical dilation: burst frequency (bursts/30 minutes), power density peak frequency, total power, and root mean squared (RMS). Statistical differences were determined by one-way ANOVA and Pearson's correlation coefficient to determine data linear relationships to consider significance (<0.05).

Results: All EMG characteristics progressively and significantly increased ($P<0.001$) during cervical dilation. In another group (Study 2), cervical dilation and power values were obtained from linear regression analysis of EMG power vs. effacement and cervical dilation. Study 2 demonstrated the mathematical relationship between EMG activity and cervical dilation.

Conclusions: 1. Electrical activity (burst characteristics) directly dictate contractions of the uterus and thereby indirectly regulate cervical effacement and dilation; 2. Analysis of uterine electrical activity by EMG can be used to monitor uterine contractions and cervical dilation, the two cardinal signs for the onset and progress of labor. 3. The relationship between burst characteristics and cervical dilation indicate that burst characteristics can be predictive of cervical dilation and similarly cervical dilation can be predictive of electrical activity and thus contractions. 4. This study has many potential benefits for pregnant women and their babies for better monitoring the advancement or progress of labor.

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Background

Parturition or the process of labor and delivery

It is first important to outline the progression of changes that occur within the uterus during pregnancy. From this, we can delve into the mechanism by which the uterus works and how we can develop an objective measure to assess the uterus, and by extension, variables that occur during labor.

The uterus grows tremendously during pregnancy from the nonpregnant state to accommodate the growing fetus and provide nourishment while essentially remaining quiescent. At the end of pregnancy, when the fetus can survive outside the mother, the uterus undergoes four physiologic phases during pregnancy each of these is marked by molecular and chemoreceptor variations which result in the transitions between the phases. The first phase known as phase 0 is an inhibitory or quiescent phase, as above. The majority of pregnancy occurs within this phase. Many known inhibitors are released during this phase such as progesterone, prostaglandins, relaxin, and nitric oxide. (1)

As the patient approaches term, myometrial activation occurs. Hormones known as uterotropins, such as an increase in estrogen are released resulting in increased expression of proteins within the myometrium; contraction-associated proteins which are receptors for oxytocin and ion channels. The increase of ion channels and gap junctions facilitate excitation and propagation of electrical signals to produce more forceful and rhythmic contractions. (2,3)

Now that the uterine smooth muscle is physiologically primed, stimulation can occur leading to augmentation of contraction by uterotonics. leading to involution. The final phase of uterine change is the continued action of oxytocin leading to the involution of the uterus.

Parturition is believed to occur at term and sometimes preterm facilitating the transition from uterine quiescence to forceful contractions. There are many feedback loops, hormonal signals and other systems/mechanisms that work as fail-safes to ensure there is a proper transition from quiescence into normal physiologic labor. (3)

Labor is a three-stage process, with lines that define the transition from one stage to another. The first stage is marked by two phases a latent and active phase as established by Friedman. Friedman defined “normal labor" in the mid-'50s when he assessed the progression of labor in 500 primigravida women. By analyzing this data, he established the “Friedman curve” which outlined the progression of labor within the first stage as it enters the second stage of labor.

Although there is literature that shows some deviation from Friedman’s original findings that progression is considered the same with variations on the inflection point that marks the transition from latent to active phase.

Nonetheless, what he found is that the initiation of the slower latent phase occurs when the cervix starts to undergo two changes. These changes collectively are referred to as the ripening of the cervix. This two-character process involves the effacement and dilation of the cervix. The latent phase ends at approximately 5 cm of dilation, and transitions to a more rapid active phase, where an inflection in dilation to a more rapid rate occurs culminating at 10 cm of dilation (full dilation) and 100% effacement. (4,5)

The second stage of labor begins at complete cervical dilation (i.e. 10 cm) and continues with voluntary contraction of abdominal muscles to the delivery of the fetus, and the third stage of labor occurs after fetal deliver until placental expulsion. (6)

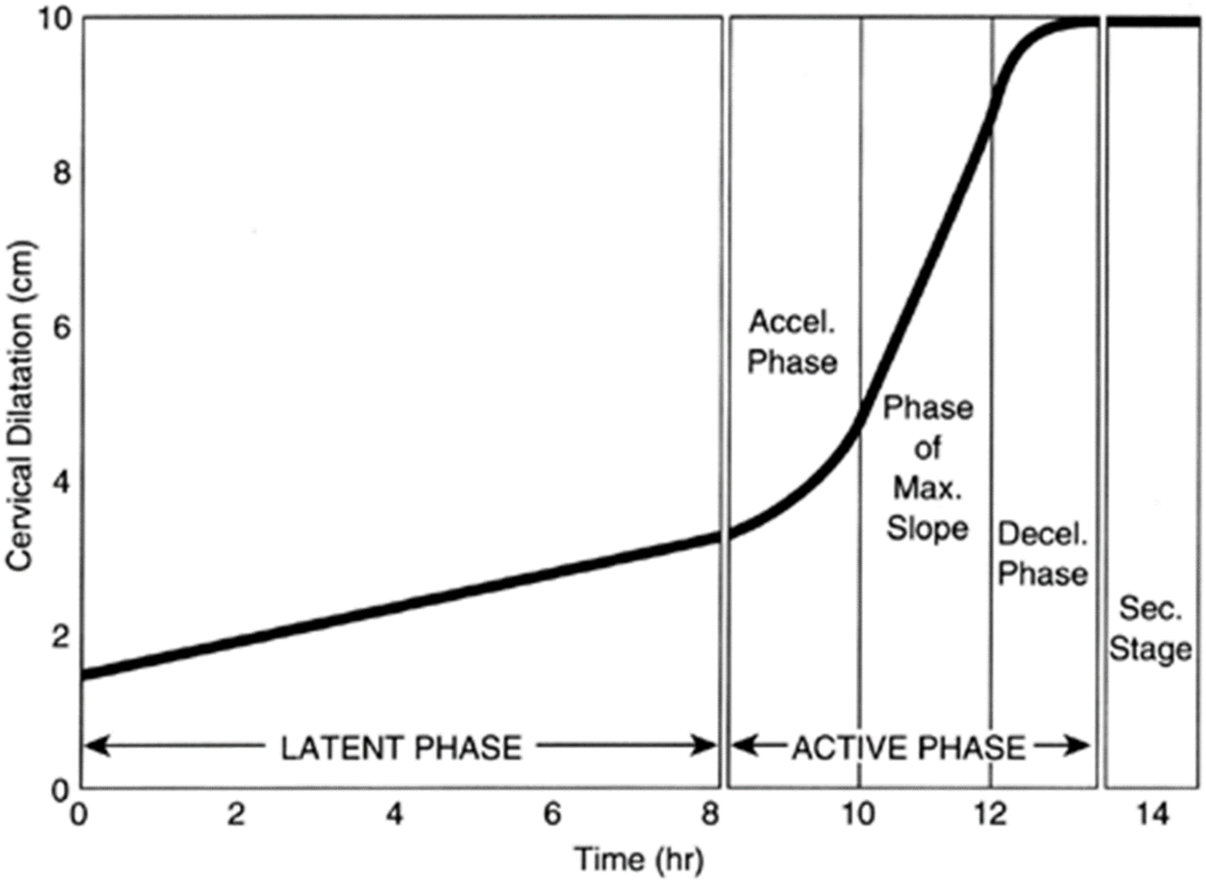


Figure 1: Friedman’s Curve (1954) - Friedman performed a study which defined the spectrum of normal labor which relates time vs. cervical dilation. He assessed 500 primigravid patient’s cervical dilation progression over time. Documenting at transition from a slower Latent phase to a faster active phase. His data suggested that there was a transition at approximately 3-4 cm. Upon transition the approximate rate of dilation was 1.2 cm/hr. (4)

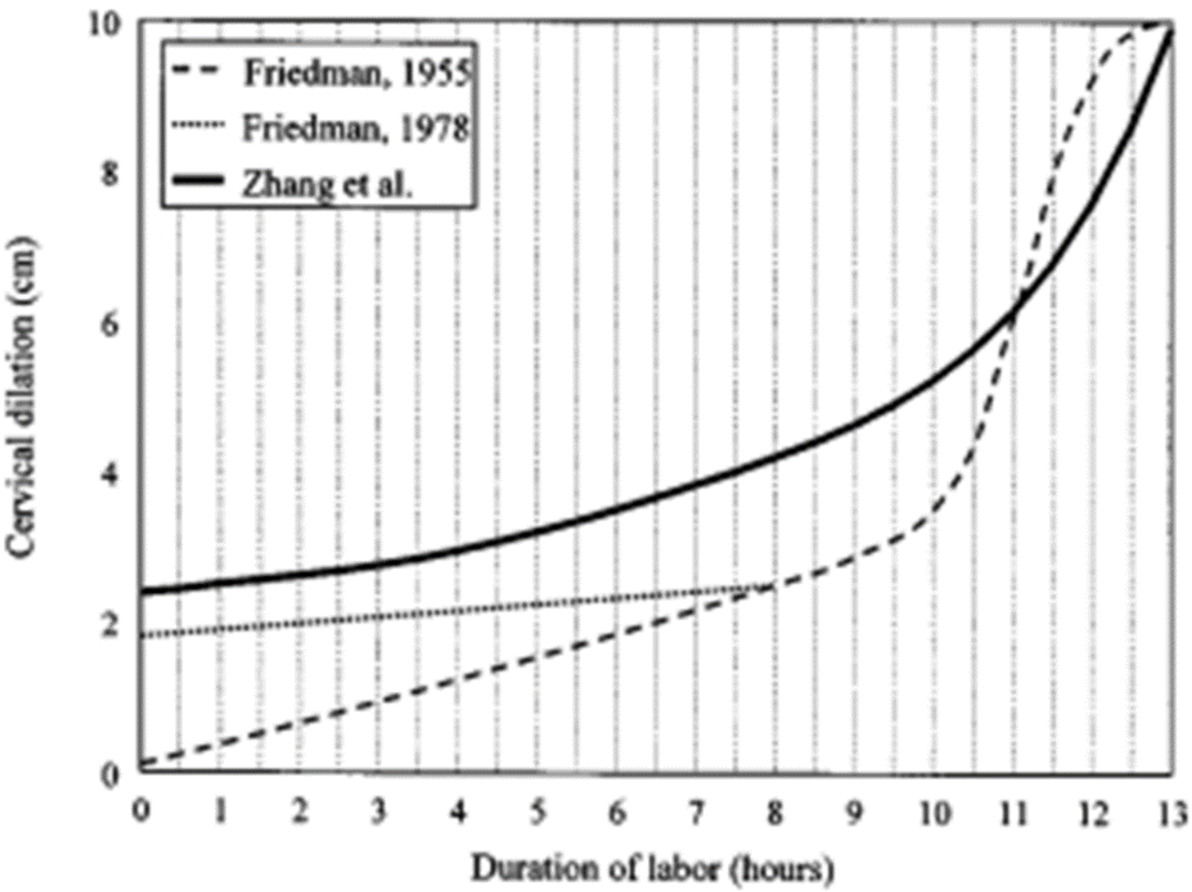


Figure 2: Zhang's Curve (2010) - Zhang et al. performed a similar study as Friedman, using 62,415 participants. His findings had also shown that there was a relatively slow progression in cervical dilation (latent phase). However, Zhang's labor curve demonstrated an a more gradual increase cervical dilation rate. Most patients did not reach >1cm/hr. until the cervix dilated to 5-6 cm (active phase). Unlike Friedman, Zhang did not observe a deceleration phase. (5)

Subjective Digital Examination

Assessment of cervical dilation and effacement along with other characteristics are determined with a digital examination. These assessments are performed during different stages of the admission process, to include at admission, at frequent intervals during the first stage of labor, and when a fetal heart rhythm anomaly is observed. Studies have shown that the digital method of assessment is inaccurate and varies among practitioners. (7) As a result of this inaccuracy, studies have further found that this is not a reliable method by which to diagnose true term or preterm labor. Additionally, it has been shown that patients receive unnecessary treatments and inaccurate doses of uterotonics and oxytocic's because of subjective measuring variations. Furthermore, depending on the subjective findings of the practitioners, studies have found that patients have undergone an increase in unnecessary Cesarean sections with decreasing attempts of trial of labor after Cesarean section further leading to high numbers of Cesarean sections. (8-12)

Pre-Term Labor

When reviewing medical literature, a line seems to continually repeat itself regarding pre-term labor, "Identifying women with preterm contractions who will go on to deliver preterm is an inexact process, even though preterm labor is one of the most common reasons for hospitalization of pregnant women." (13) This inability to reliably distinguish true vs. false preterm labor is one of the biggest diagnostic problems in obstetrics today. Upwards of fifty percent of women who are assessed for preterm labor, end up not being in preterm labor, furthermore, going on to deliver at term. (8)

Further complicating matters, twenty percent of symptomatic women, that were believed to be in preterm labor but unable to be definitively diagnosed go on to deliver without appropriate treatment resulting in categorical disabilities such as, neurologic, mental, behavioral, and pulmonary. (10) As a result, we under and over prescribe unnecessary treatments and blunder opportunities to provide optimal neonatal care, e.g. tocolytics and steroid therapy. Sadly, these inaccuracies result in 85% of perinatal deaths. (14)

The determination of preterm labor is based on the clinician's history and physical, followed by a speculum exam to assess for cervical changes and other pathology and a digital exam for characteristics previously stated. However, utilization of these variables alone in studies has proven to be subpar in the determination of preterm labor. As a significant percentage of women with noticeable cervical change still do not enter pre-term labor even without the utilization of tocolytics. (15)

Myometrium

The mechanism behind EMG is a result of normal uterine physiology. Electrical signals of the muscle of the uterus (the myometrium) are the underlying cause of uterine or myometrial contractions and can be measured with EMG. The rate and duration of electrical bursts are directly related to the frequency and length of contractions, whereas the magnitude of contractions is proportional to the spread or propagation of the bursts to and recruitment of more muscle cells. There are several characteristics of which are important in understanding the mechanism of EMG. The excitability of myometrial cells works via stimulatory and inhibitory signaling. The stimulation leads to excitability within the cells because of changes in the transduction across the membranes via synthesis of transmembrane protein structures such as ion channels, gap junctions, and uterotonic receptors. (29, 36, 37)

The formation of gap junction proteins allows for coupling between the myometrial cells, facilitating the propagation of action potentials between myometrial cells. Throughout most of the pregnancy these proteins are lacking or are in short supply, not inhibiting, but instead lack the proper means to propagate signals for contractions sufficient enough for expulsion, resulting in a quiescent uterus, that maintains and nurtures a fetus. (38, 39)

As term approaches the cells begin to form a syncytium via the synthesis of proteins resulting in effective contractions. Their formation leads to voltage-dependent $Ca2+$ channels which now can open, the $Ca2+$ is able to enter muscle cells and act on the myofilaments, the gap junctions allow the flow of $Ca2+$ to move down an electrochemical gradient activation more myofilaments at neighboring myometrial cells provoking coordinated contractions. (40) The resulting change in voltage across the cells can be measured with prior studies showing that the human uterus operates at an approximate frequency rate of 0.34-1.00 Hz after filtering out other signal, skeletal muscle and other noise artifacts. (32, 41)

Electromyography (EMG)

It has been thoroughly established that the depolarization-repolarization of uterine smooth-muscle myometrial cells results in a large scale and progressive uterine contractions. (16) When the depolarization-repolarization of these myometrial cells works together and in series they form bursts of activity. On EMG this is viewed as spikes in voltage readings (~1mV) and reaching levels that exceed background readings. During pregnancy, these readings can last approx. a minute and are not coordinated enough to result in progression to labor, but as the pregnancy continues the bursts become more coordinated escalating during labor. (17, 18)

As previously eluded to, the voltage of myometrial cells can be read via EMG. There have been multiple EMG devices to access these values some of which were invasive requiring needled probes to take readings. This, unfortunately, has the risk of introducing infection as well as discomfort to the patient beyond that physiologic pains caused by labor. There are devices that have eliminated the risk of infection by removing these probes and instead implementing abdominal surface electrodes or leads, in addition to eliminating the discomfort patients of other types of recordings (19-23).

Studies have found that EMG is more reliable than tocography (TOCO) and Intrauterine Pressure Catheter (IUP or IUPC), the former being the standard for the past 40+ years, despite not being properly vetted to today's standards. (24-27) It is known that TOCO measures the shape of the abdominal as a function of uterine contractions and not the electrical activity of the uterus. This results in a qualitative method of measurement and not a quantitative one. (28) This unfortunately limits its application in assessing true (active labor) labor regardless of it being term or preterm. (27, 28-30) In making note of the IUPC, although it does assess the contraction in a quantitative manner via readings of the pressure of the amniotic fluid. It is limited in that uterine membranes must have to be ruptured, and the device is invasive, which carries a risk for both mother and baby.

As figure 3 shows, an EMG record and the relationship of EMG burst patterns to IUP and TOCO in a single patient. EMG can assess uterine contractions and is more accurate than the IUP or TOCO. EMG reads the electrical changes in the myometrial cells. Due to its non-invasive application, we can monitor the onset of true labor at term or preterm (19, 21, 31-34). Thus, it has been shown that different objective units of measure from electrical bursts such as power spectrum peak frequency, amplitude, propagation velocity of uterine electrical signals all designate the onset of true labor as shown in Figure. (31, 34, 35)

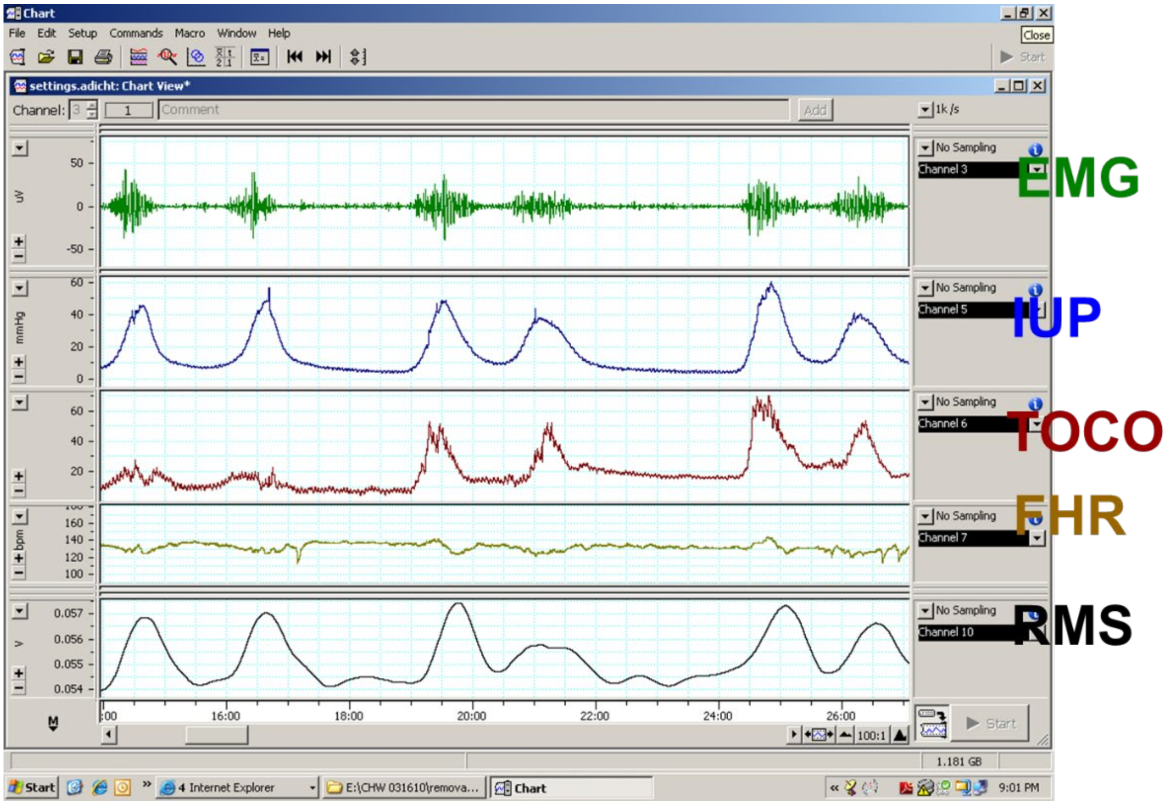
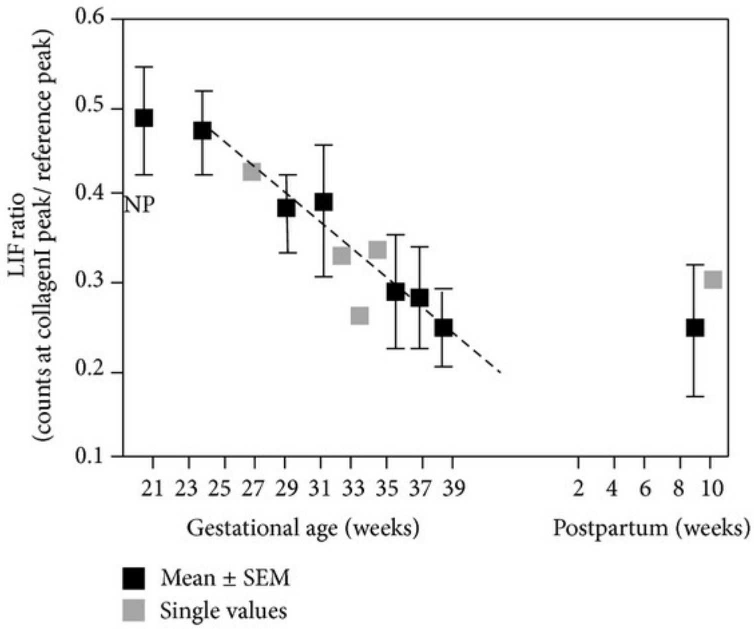
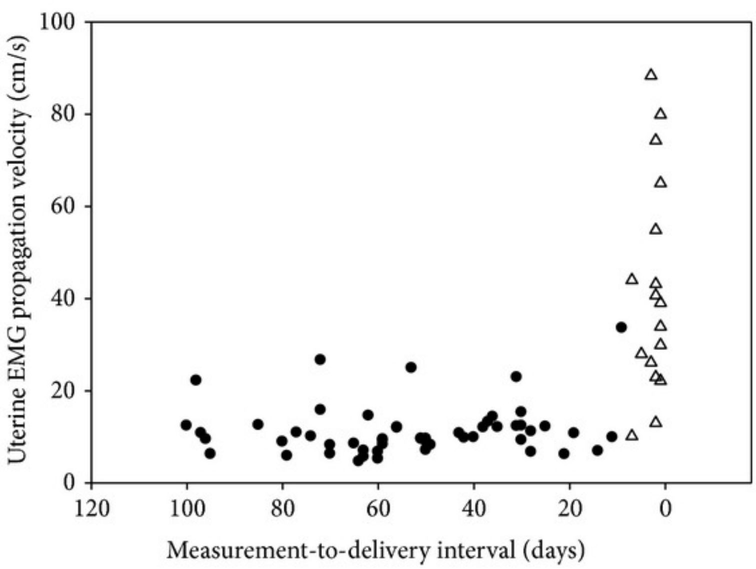


Figure 3: Recording of electrical activity (bursts, top tracing) corresponds to contractions measured with IUP (intrauterine pressure), TOCO and RMS (route mean squared) in patient during 1st stage of labor. X axis is time measured in minutes. Fetal heart rate (FHR) is an estimate of fetal wellbeing. Note how bursts relate to IUP and RMS but not always TOCO. (19)

4a).



(a)



(b)

Figure 4a: Cervical light-induced fluorescence (LIF) ratio throughout human pregnancy and postpartum. NP: nonpregnant; Figure 4b uterine EMG propagation velocity increases immediately prior to delivery. Δ delivery ≤ 7 days from the measurement; ● delivery > 7 days from the measurement. Based on data from Schlembach et al. [28] and Lucovnik et al. [19]. Figure 4a shows that the cervical collagen decreases progressively throughout pregnancy and thus the cervix softens during the progression of pregnancy. Figure 4b demonstrates that EMG activity, which produces strong uterine contractions begins following cervical softening (Figure 4a).

This may suggest that EMG is a valuable tool in distinguishing spontaneous true labors and furthermore how to treat patients.

Sadly, cesarean section rates are on the rise worldwide more so in middle and high-income countries, made worse as 1) many of these procedures are performed during the latent phase of labor and 2) trial of labor after cesareans are on the decline (42-47). These results suggest that either patients or physicians are developing poor practices in just repeating cesareans after prior procedures. The only remedy would be to prevent these procedures in the first place. This is not to say that cesareans are not necessary, as the arrest of labor is a complication that would require oxytocics and potentially cesarean sections. However, I hope I have convinced you that our current methods for determination of true labor, term vs. preterm, and arrest of labor are inadequate and inaccurate and that the field of obstetrics needs to look to a form of objective measure that better quantitively supports the medical decision making made by our practitioners.

Aims of study

The goals of this study were to assess: 1) The potential for measuring uterine electrical activity during the 1st stage of labor as the basis for contractility of the uterus; 2) The causal relationship of contractility to and changes in cervical effacement and dilation in pregnant patients, and 3) Define how predicted values of cervical dilation can be obtained from electrical signals and how predicted values of electrical signal characteristics can be obtained from cervical dilation. Prior studies have shown that there is a distinct difference in the onset of preterm (7 days) vs. term labor (3 days) electrical signal propagation via the previously stated characteristics of EMG. (31, 34)

Methods

Patient recruitment and enrollment was from Guangzhou Women and Children's Hospital, Guangzhou Medical University, Guangzhou, China using an established protocol approved by the Institutional Review Board (IRB) during the period from September 2016 until September 2017. under the guidance of Dr, R.E. Garfield. All patients (n = 195) were Chinese between the ages of 18 to 36 years old in their first pregnancy (i.e. nulliparous patients). Cervical dilation was assessed by digital cervical exams, the only procedure presently accepted for measurement of cervical dilation. Cervical dilation was assessed only at one time period for each patient, from the noneffacement to full dilation at 10 cm because multiple longitudinal measurements on the same patient is discouraged. Similarly, EMG records of at least 30 recording time were obtained from patients at the same period as the cervical exam for dilation.

Electrode attachment sites were prepared by first cleaning away excess oil with alcohol prep pads and then using a mild abrasive and impedance-reducing get to gently rub off the outer layers of the skin, improving electrical conduction of the electrode. The electrodes were self-adhesive Ag2Cl models, each approximately 1.65 cm2 in area (Quinton, Bothell, Wash). Two sets of these bipolar electrodes were attached to the abdomen near the navel. Each electrode was separated from its respective partner by about 3 cm. Grounding was accomplished by placing another lead laterally on the patient's hip. See figure 5 for photo of electrodes on the abdominal surface.

The patients were asked to lie supine and very still to reduce any movement artifact (labor patients were in the first stage of labor, i.e. Not pushing) The differential signal was analog band-pass filtered from 0.01 Hz to 1.00 Hz to remove unwanted signal components and to prevent aliasing. The information was then amplified and stored on a personal computer. (Comparing uterine electromyography activity of antepartum patients versus term labor patients)

EMG records from nulliparous pregnant women with normal progression of 1st stage labor and vaginal delivery were used in this study. A single measurement of EMG activity at least 30 minutes in duration was taken from electrodes placed noninvasively on the abdominal surface sometime during labor, whether before or following 100% effacement and up to 10cm dilation.

Uterine electrical bursts, which are known to produce uterine contractions, were measured and analyzed via ADInstruments (Castle Hill, Australia) equipment and software. The bursts characteristics were recorded and analyzed to obtain values of bursts/30 minutes (min), power density peak frequency, route mean square (RMS) and total power.

Plots of cervical dilation (x-axis) vs. each burst characteristic (y-axis) record were made. To estimate relationships between power of EMG and effacement and cervical dilation linear regression analysis was used. To obtain predictive values of cervical dilation from values of power (x-axis) or to obtain predictive values of power (y-axis) from cervical dilation lines were drawn to connect points on the linear regression line using the formula $y = a + bx$, where x and y are the variables, b is the slope of the regression line and a is the intercept point of the regression line with the y axis.

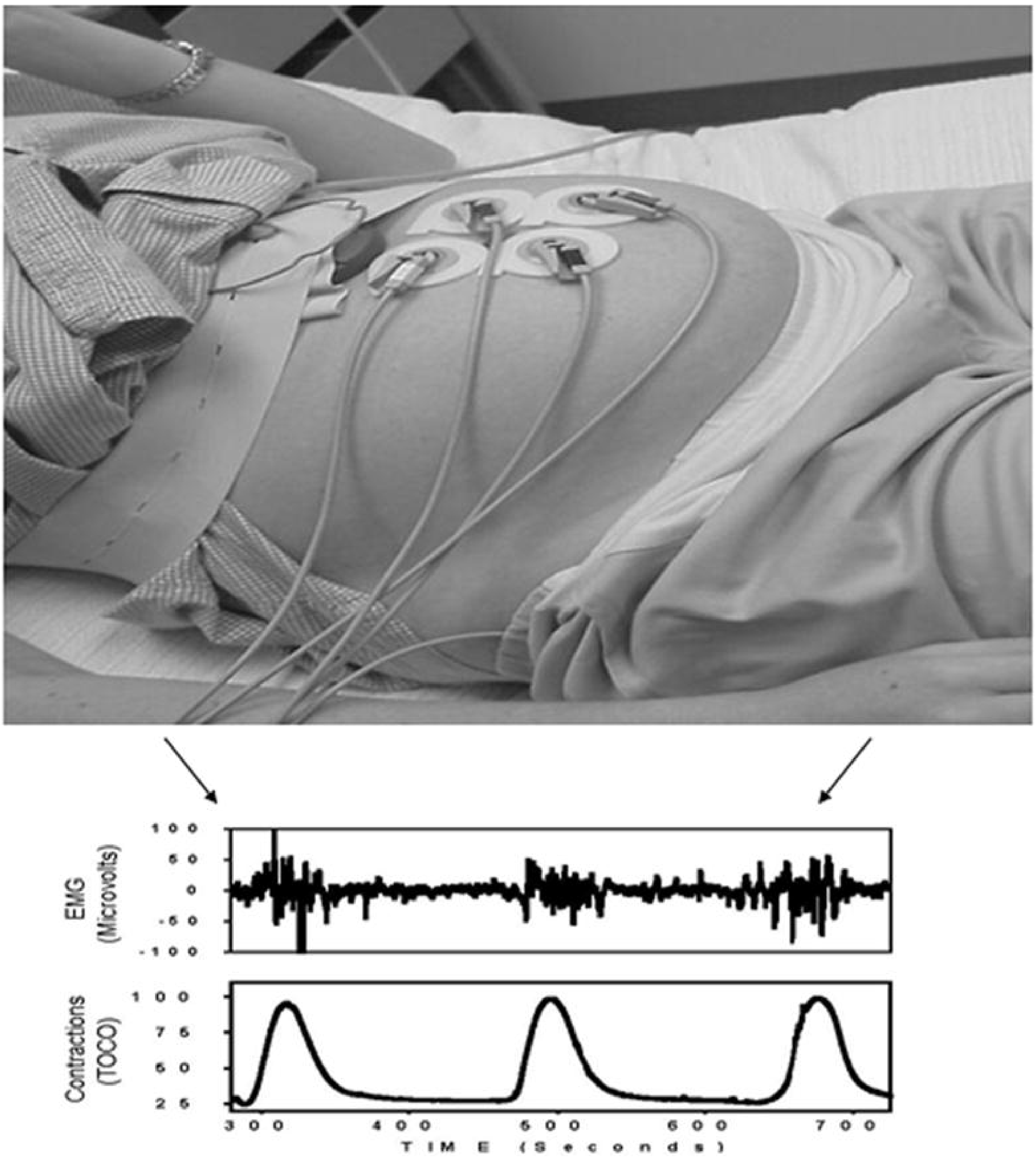


Figure 5. Photo of abdominal surface of pregnant patient to show placement of EMG electrodes (upper photo). Lower figure shows 3 representative electrical bursts corresponding to contractions measured with a TOCO when using the above arrangement of electrodes.

Results

Uterine electrical bursts were measured and analyzed via ADInstruments (Castle Hill, Australia) equipment and software the bursts characteristics were recorded and analyzed to obtain values of bursts/30minutes, Power (min), and Power Density Peak Frequency.

Figure 6 shows the relationship of effacement and cervical dilation (x axis) vs. number of bursts per 30 minutes (y axis). The plotted line is not exactly linear compared to the linear regression line but nevertheless the burst number increases progressively as the cervix dilates. $y=1.6913x - 1.7157$, the linear regression line (or dotted-line), is determined from mean data and gives the approximate increase of burst per 30 minutes as the cervix dilates. R^2=~0.86 is our coefficient of determination, explaining some of the variability. A statistical significance of $P<0.01$ was determined. The data was recalculated so that a noneffaced cervix is zero.

The relationship between the electrical burst power vs. effacement (y-axis) and cervical dilation (x-axis) during 1st stage of labor is shown in figure 7. The plotted line is relatively linear compared to the linear regression line and both increase as cervical dilation increases. The linear regression line $y=4.3175x-6.9795$ is determined from mean data and gives the approximate increase of electrical burst power as the cervix continues to dilate. A coefficient of determination $R^2=0.86$ explains some of the variability. A $P<0.01$ was calculated using the mean data. The data was recalculated so that a noneffaced cervix is zero.

Cervical dilation (x-axis) vs. Burst Duration (y-axis) was plotted in figure 8. The plotted line does not increase linearly. The linear regression line was determined from mean data and is plotted in comparison to the mean data points. $y=2.5912x + 3.4483$ was determined from the mean plotted data. The burst duration is in seconds. A coefficient of determination $R^2=0.44$. A significance of $P<0.01$ was determined. The data was recalculated so that a noneffaced cervix is zero. Cervical dilation (x-axis) vs. RMS (y-axis) is shown in figure 9. It appears to increase in a linear fashion. The dotted line is the linear regression line that shows the average rate of increase as the cervix dilates. The linear regression line equals $y = 0.0133x + 0.034$. A coefficient of determination of $R^2=0.80$ was determined. A significance of $p<0.01$ was found. The data was recalculated so that a noneffaced cervix is zero.

Figure 10 shows a plot of Power density spectrum (PDS) peak frequency (y axis) vs. effacement and cervical dilation (x axis) relationship. Regression Analysis demonstrates significant differences $P<0.01$. There appears to be an increase in a linear fashion. The linear regression line or the dotted line is $y = 0.057x – 0.073$. This figure demonstrates that it is possible to obtain either x values from y values or y values from x values using linear regression analysis and the formula $y = a + bx$, where x and y are the variables, b = the slope of the regression line and a = the intercept point of the regression line and the y axis. R^2=.95 The data was recalculated so that a noneffaced cervix is zero.

Duration of the electrical bursts was recorded, a significant increase in duration of burst was recorded after effacement and during cervical dilation. Further analysis may be warranted to assess the linear change of the duration of electrical bursts after effacement or only during cervical dilation.

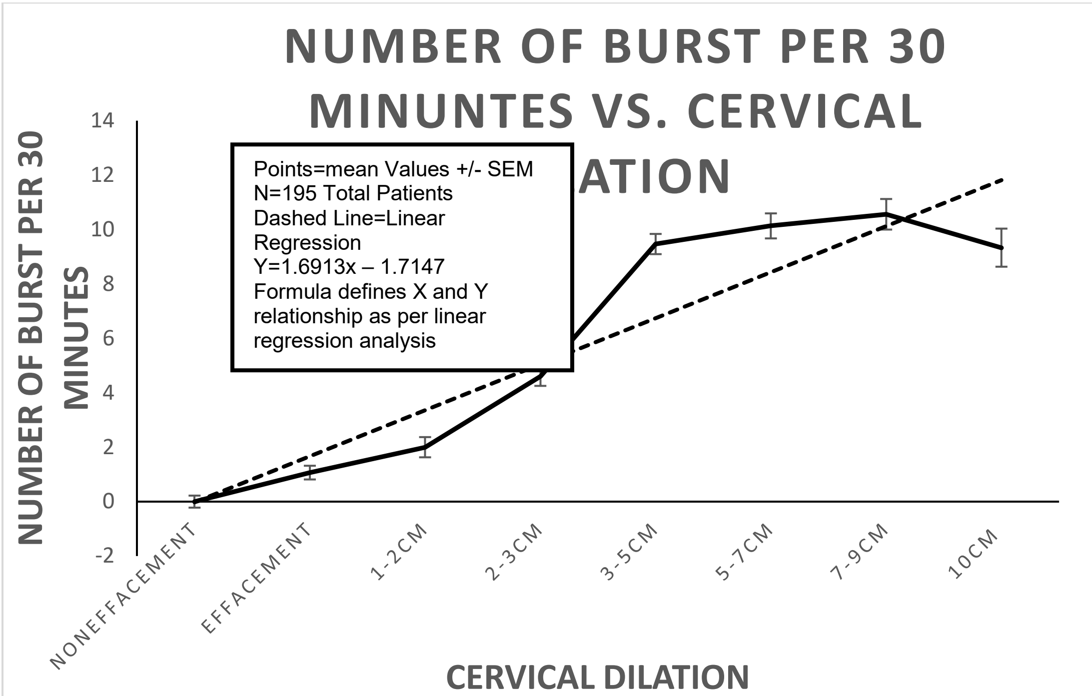


Figure 6: Each point represents mean values +/- SEM present, Dashed line = linear regression line from analysis of each point in graph. Plot of electrical burst number per 30 minutes vs. effacement and cervical dilation during 1st. stage of labor. Linear Regression Analysis demonstrates significant differences P<0.01. Power –Regression Analysis demonstrates significance P<0.01.

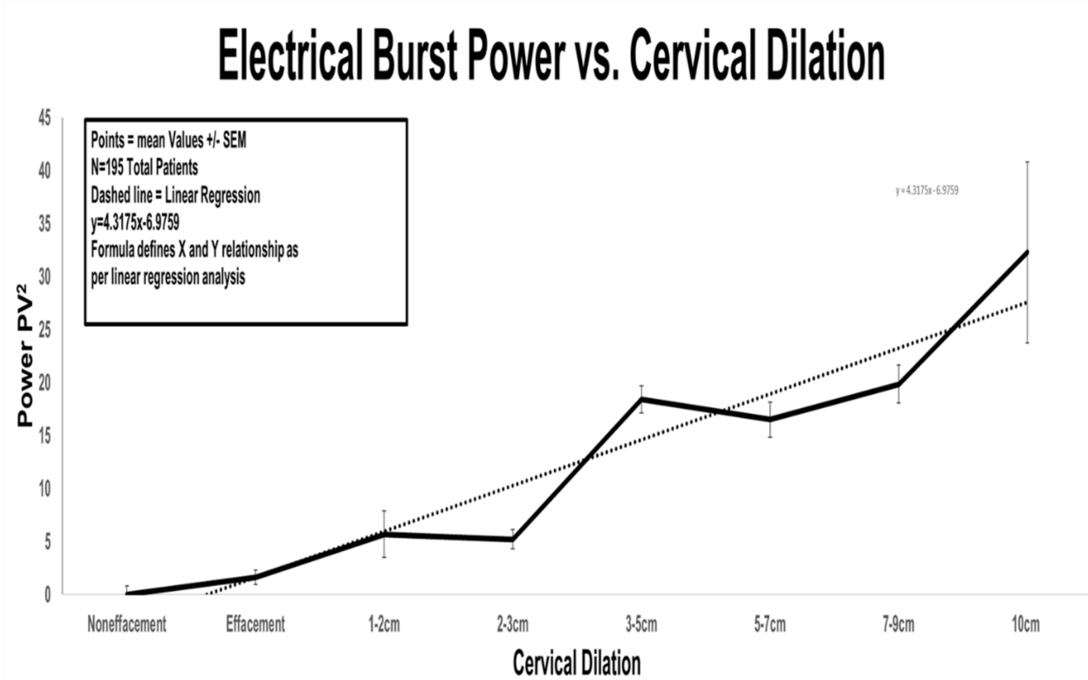


Figure 7: Plot of electrical burst power vs. effacement and cervical dilation. Regression Analysis demonstrates significant differences P<0.01. Means +/- Standard Error of mean plotted. Data points representative of the mean for data collected. Linear Regression line determined and shown, with Equation for linear regression line. X-axis 1 point = 1 Hz, R^2=0.86

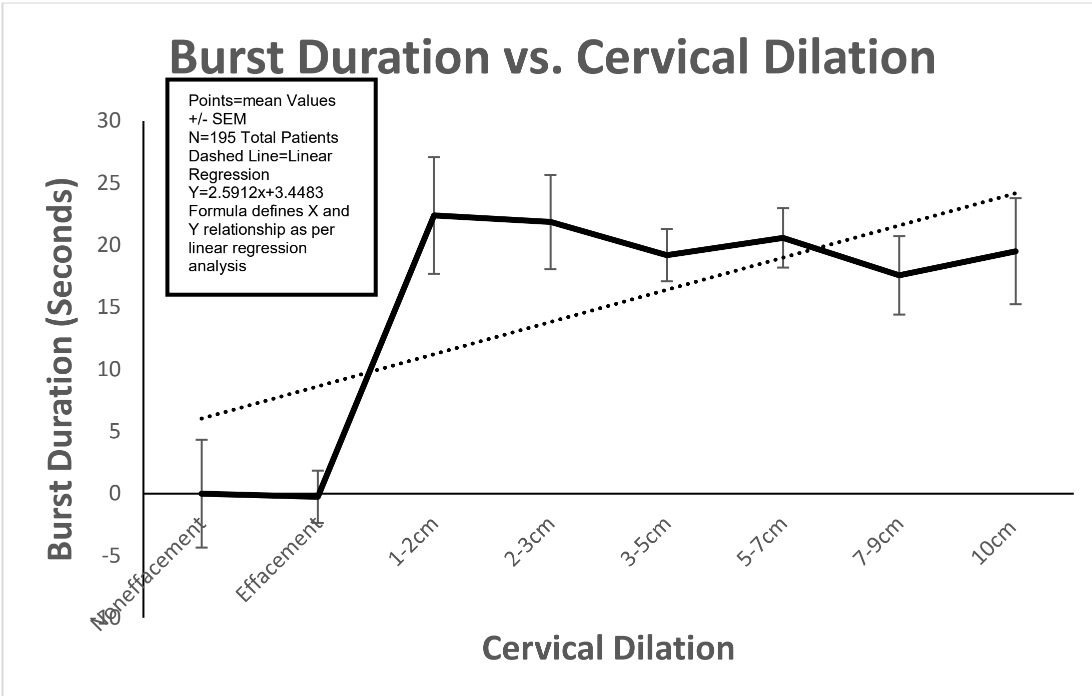


Figure 8: Plot of duration of electrical burst duration in seconds vs. effacement and cervical dilation. Regression Analysis demonstrates significant differences P<0.01. Means and Standard Error plotted. Data points representative of the mean for data collected. Linear Regression line determined and shown, with equation for linear regression line.

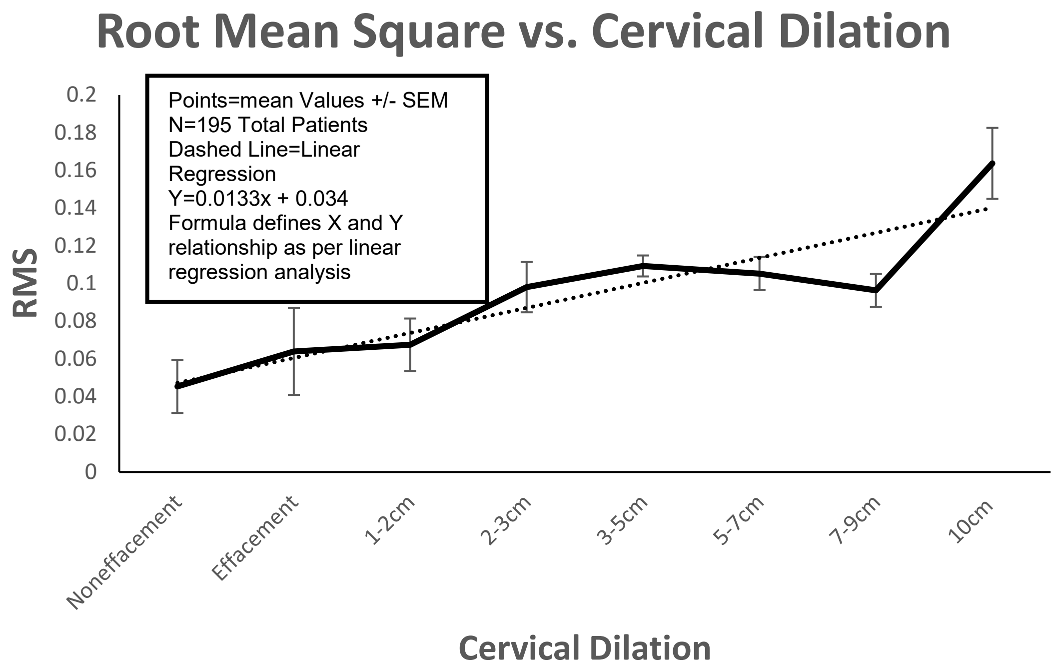


Figure 9: Plot of RMS vs. effacement and cervical dilation during 1st. stage of labor. Each point represents mean values +/- SEM present, Dashed line = linear regression line from analysis of each point in graph. Linear Regression Analysis demonstrates significant differences P<0.01. R^2=0.803

Power Density Spectrum – A plot of Power density spectrum (PDS) peak frequency against effacement and cervical dilation demonstrates significance, $P<0.01$, as a linear model. This model demonstrates that it is possible to determine a PDS value from a known cervical dilation value or determine the anticipated cervical dilation value from PDS values using linear regression analysis.

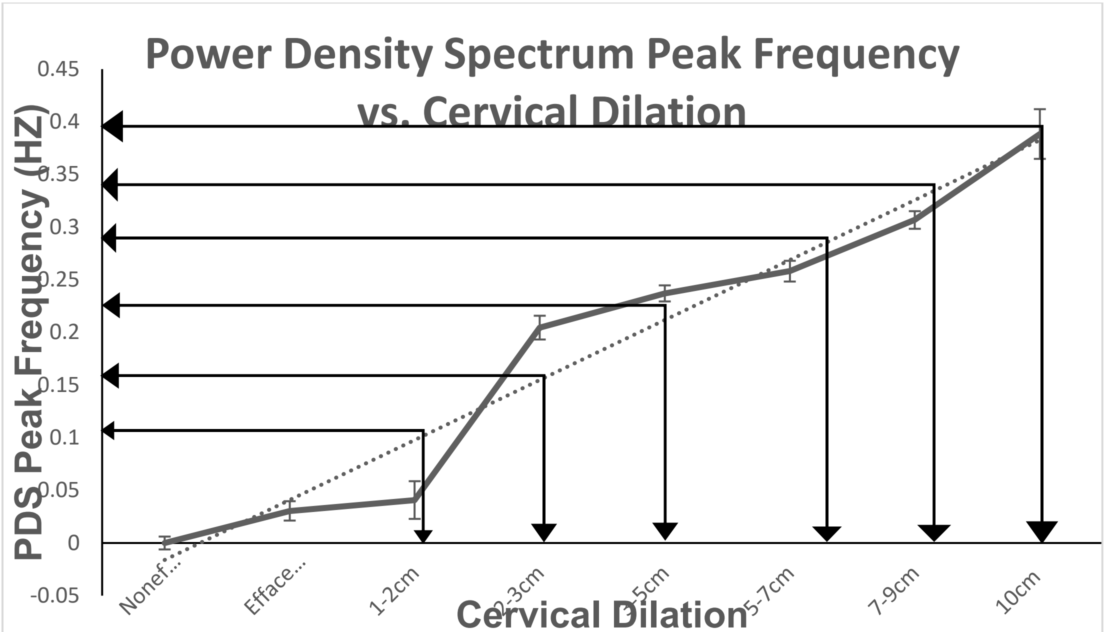


Figure 10: Plot of Power density spectrum (PDS) peak frequency (y axis) vs. effacement and cervical dilation (x axis) relationship. Regression Analysis demonstrates significant differences P<0.01 This figure demonstrates that it is possible to obtain either x values from y values or y values from x values using linear regression analysis and the formula y = a + bx, where x and y are the variables, b = the slope of the regression line and a = the intercept point of the regression line and the y axis. R^2=.95

Table 1

Cervical Dilation ⟷	**Power Density Spectrum**
1 cm	**~0.00Hz**
1.39 cm	**0.01Hz**
2 cm	**0.04Hz**
2.18 cm	**0.51 Hz**
2.83 cm	**0.09Hz**
3 cm	**0.1Hz**
4 cm	**0.16Hz**
5 cm	**0.21Hz**
5.69 cm	**0.25Hz**
6 cm	**0.27Hz**
6.9 cm	**0.32 Hz**
7 cm	**0.33Hz**
8 cm	**0.38Hz**
9 cm	**0.44Hz**
10 cm	**0.50Hz**

Table 1: The Relationship between cervical dilation and power density spectrum values. Utilizing linear regression analysis and values from cervical dilation, we're able to determine Power Density Spectrum (EMG) values. (as also seen in figure 10). Similarly, approximate EMG dilation values can be estimated from Power Density Spectrum values.

Discussion

This unique study, utilizing electromyography methods on a large population of pregnant women in the first stage of labor, demonstrates that electrical burst patterns, which directly dictate contractions of the uterus, are also related to the dilation of the cervix. All electrical burst characteristics, such as number of burst/30 minutes, power, duration, amplitude and the calculated route mean squared (a surrogate measurement of amplitude of contractility), increase progressively as the cervix slowly dilates from the noneffacement state to effacement (thinning) and through dilation from 1 to 10 cm. These observations suggest that uterine contractions are responsible for cervical effacement and dilation. These data clearly indicate electrical activity of uterine muscle (i.e. myometrium) not only regulates contractility of the uterus but also the effacement and dilation of the cervix. Thus, the two signs for the onset and progress of labor, uterine contractions and cervical dilation, are regulated by electrical activity of the uterus. These conclusions have profound influence on our understanding of the process of parturition and on ways to evaluate and control labor and delivery.

As discussed in the background section, the current standard of uterine contractility during the 1st stage of labor is grossly inadequate. (7-12) Whether as a result of inaccuracy or invasive risk factors, many studies acknowledge we need a new method that overcomes these shortcomings.

Historically, physicians and researchers with the field have identified Electromyography as an accurate method to assess uterine contractility and with the inclusion of this study cervical dilation. (26,27, 31, and 34) Thereby providing an alternative means to the current standards. Methods of the past have fallen short historically. Prior to the implementation of electrodes, invasive probs were utilitzes. (31 & 34) This was not well received by patients, and still carried the same risks as other invasive procedures.

Our study implements electrodes, which eliminates those risk factors and is more tolerable to patients. The results of this study show that implementation of electrodes is consistent with current standards as seen in figure 5. In addition, multiple variables (figures 5-9) provide a more detailed picture of uterine contractility and cervical dilation.

As discussed in earlier section cervical dilation and uterine contractility are closely regulated to insure successful delivery of the fetus. (2,3) The cervix ripens in response to multiple factors during the initiation of labor to include prostaglandins, oxytocin and uterine contractions. (7, 48) This is a result of the increase in a variety of proteins that increase the contractile capacity of the uterus. The results of this study show that contraction and electrical activity may play a bigger role than previous thought. As seen in figures 5-9, the increase in electrical activity as seen in the EMG readings positively correlates to an increase in effacement and dilation of the cervix. The use of oxytotics in arrest of labor is already being implemented within physician practices, but it should be noted that there is drastic variability between these practices. The use of EMG as continuous monitoring system would allow a more unanimous definition of arrest of labor on a real time scale to allow physician to determine when oxytotics should be implemented, but furthermore it should allow us to better determine on a patient to patient basis, the best dosing required to treat arrest of labor. This concept would also work for oxylytic therapy in true preterm labor. Although dilation and uterine contractility increased during 1st stage of labor there is generally little information to link the two events together casually. When looking at Friedman's and Zhang's research on the transition from latent into to active labor. (4 & 5) We see that figure 6,7, and 10 that there is a drastic pickup in registered electrical activity. This could be the underlying mechanism that validates and defines the transition that both Friedman and Zhang described. The variation between their results does suggest that more research must be performed to try and distinguish the variability between their results. This could be the difference of multiparous vs primigravid patients.

Future studies, that we are currently looking into would help in the development of guidelines with use of EMG devices and determining the cervical ripening, and transition from latent to active labor based on patient's obstetric history.

The figures shown in this study (Figures 6 to 10) illustrate the relationship of various electrical burst characteristics vs. effacement and cervical dilation. For the most part the parameters in the figures are linearly related and can be defined by linear equations, example $y = mx + b$, where x and y are respectively x and y values, m = slope of line and b is the y intercept. However, some of the characteristics are not exactly linear, particularly the duration increases dramatically from low to high values with cervical dilation (Figure 8) and frequency bursts/ 30 minutes which rises in a linear manner and then tails off at higher cervical dilations. It should be noted that the slope of the regression line for each characteristic is different perhaps indicating that multiply pathways control each independent characteristic. Thus, this is not surprising since many mechanisms of excitation and propagation of the electrical signals are involved.

Burst Duration is not linear (Figure 8). However, it provides us with important information about the sudden onset of increase duration of bursts, in seconds, when labor progresses from noneffacement to effacement to cervical dilation. It could be possible that with multivariant analysis the burst duration would be more telling of true labor vs. false labor.

RMS or intensity follows a linear progression (Figure 9) and suggests that as labor progresses the intensity of contractions increase as a result of increase electrical activity within the uterus. It is noted that as the uterus approaches 10cm there is a drastic increase in intensity. This may represent a maximal effort by the uterus to expel the fetus. This could be something to study in animal models to see if there is a greater level of intensity that could be found, if for example there was macrocephaly or a large for gestational age fetus. If true, this would better help us understand when an emergent Cesarean section would be warranted.

It should be noted that we aren't suggesting that the current methods of cervical assessment should be halted but supplemented. The predicted EMG value can be determined from cervical dilation as shown in figure 10. Table 1 further demonstrates this as EMG values can be calculated via linear regression to determine the expected cervical dilation. This concept should work in reverse, when clinically obtaining a subjective cervical dilation, we can provide objective support to the findings by calculating the EMG ensuring its accuracy (shown by table title double arrow). An clinical example would be upon establishment of a standard range for arrest of labor by EMG, a clinician could obtain a series of subjective measures which would then be calculated into EMG (if EMG is not available) or then us these values as support to getting an EMG value to further support a physician's determination that a patient has truly meet the definition for arrest of labor.

Conclusions

1. Measured Uterine Electrical bursts directly dictate contractions of the uterus and therefore indirectly govern cervical effacement and dilation.
2. Analysis of EMG can be used to monitor uterine contractions and cervical dilation, the two cardinal signs for the onset and progress of labor.
3. EMG accurately tracks the onset and progress of labor.
4. The onset of the active phase of labor occurs at the time of full cervical effacement.

Recommendations

This study contains several important and significant benefits for monitoring pregnant women during the birth of their fetuses. Particularly significant are the potential abilities of EMG to identify mechanisms involved in the onset and progress of term and preterm labor, selection of treatments, improve perinatal outcomes, save costs and maternal and fetal lives. Further analytical measurements are clearly needed to define the relationship between cervical dilation and electrical activity of the uterus.

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